Bone Morphometric Parameters Accurately Predict the Apparent Mechanical Properties of Damaged Peri-Implant Bone

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Introduction

Secure fracture fixation is highly dependent on adequate primary stability of trabecular bone screws. As bone microstructure is by nature characterized by a wide variability, *in vitro* mechanical testing usually requires a large sample size to provide valid statistics. High-resolution, specimen-specific, *in silico* analysis (microFE) represents a potential complementary approach to *in vitro* mechanical testing. However, typical microstructural models overpredict the mechanical response of bone-implant systems. In previous work, we have demonstrated that this over-prediction is related to peri-implant damage due to screw insertion which usually is not considered in the microFE models. We also demonstrated that an accurate agreement with the experimental data can be obtained by including a peri-implant bone damage region (BDR) in the microFE models. However, a question that still remains is how to determine the Young's Modulus of the BDR. The aim of this study was to develop a method to accurately predict the Young's Modulus of the BDR on a specimen-specific basis by taking into account the specimen-specific morphometric bone properties.

Methods

Ten trabecular bone specimens were core-drilled from fresh-frozen human femoral heads and scanned in a µCT with 20 µm resolution. After insertion of a bone screw in each specimen, all specimens were scanned again in the µCT right before uniaxial quasistatic compression testing to failure. For the microFE simulation, E-Moduli of 120 GPa and 18 GPa were defined for the implant and bone, respectively. Then, a 0.9 mm thick BDR was defined around the implant and a discrete Young's Modulus range from 0.6-2.2 GPa (0.2 GPa/step) was chosen from which a corresponding *in silico* stiffness range was computed by the parallel FE solver 'ParoSol' (Flaig, 2012) running at the Swiss National Supercomputing Centre (CSCS). A specimen-specific Young's Modulus of the BDR was determined by b-spline interpolation to obtain a perfect match between *in vitro* and *in silico* stiffness. Bone morphometric bone properties were quantified in two volumes of interest (VOI). The first one (VOI 1) represented the entire bone sample, whereas the second one (VOI 2) represented only the bone at the implantation site before screw insertion. A stepwise multi-linear regression analysis (Matlab 2014a) was conducted to determine which morphometric parameters would yield the most accurate estimate for BDR Young's Moduli to correctly predict *in vitro* bone-implant stiffness. The criterion for the choice of best fit was root mean squared error (RMSE) for the specimen-specific BDR Young's Moduli. Furthermore, the degrees of freedom had to be above 1 to avoid over-fitting.

Results

The best linear predictive model for BDR Young's Modulus was a combination from VOI 1 and VOI 2 (Table 1) with a DOF=2. RMSE for the prediction of BDR Young's Modulus was 0.0211 GPa. The predicted BDR Young's Moduli provided a good estimate for the correct prediction of *in vitro* stiffness with R^2=0.98 and a slope of 0.94 (Fig. 1).

Morphometry	VOI 1: BiopCore	VOI 2: BiopImpl
SMI	x	x
Tb.Th.	x	x
Tb.N		x
Tb.Sp.	x	x

Emod ~ 1 + BiopCore_SMI + BiopCore_TbTh + BiopCore_TbSp + BiopImpl_TbN + BiopImpl_SMI + BiopImpl_TbTh + BiopImpl_TbSp

Table 1: A multi-linear regression model was established for the determination of the specimen-specific Young's Moduli in the peri-implant bone region. It is based on morphometric properties of the bone.

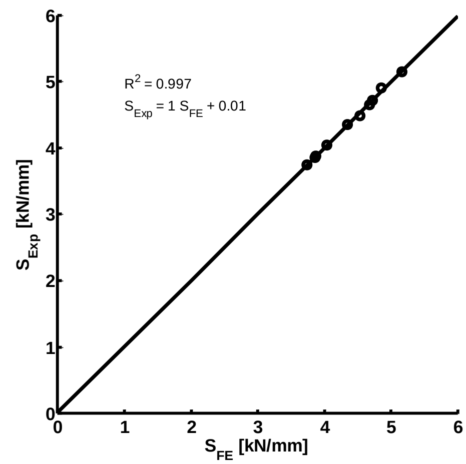

Figure 1: The micro-CT based FE model containing the determined specimen-specific Young's Moduli in the peri-implant bone region is able to accurately predict in vitro stiffness (b).

Discussion

A multi-linear regression model has been determined that links local morphometric parameters to the reduced mechanical properties of damaged peri-implant bone. By including this relationship in micro-CT based FE models the apparent stiffness of screws can be quantified accurately.

Acknowledgements

The authors acknowledge funding from the Swiss Cooperation Technology Innovation (CTI 14067.1 PFLS-LS) with Synthes as an industrial partner. Computing time was provided by the Swiss National Supercomputing Centre (CSCS).

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